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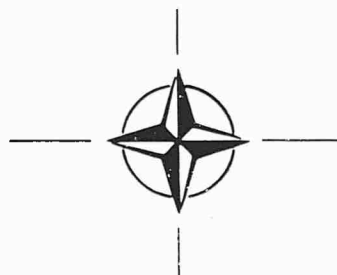
REPORT 250

**EXPERIENCE OF SUPERSONIC  
FLYING OVER LAND IN  
THE UNITED KINGDOM**

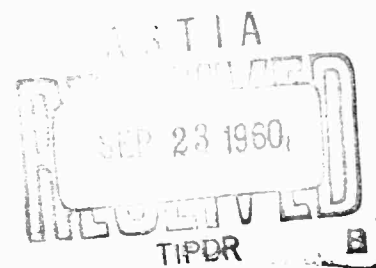
by

T. H. KERR

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NORTH ATLANTIC TREATY ORGANIZATION  
ADVISORY GROUP FOR AERONAUTICAL RESEARCH AND DEVELOPMENT

EXPERIENCE OF SUPERSONIC FLYING OVER  
LAND IN THE UNITED KINGDOM

by

T.H. Kerr

This Report was presented at the Fifteenth Meeting of the Flight Test Techniques and Instrumentation Panel, held 21-23 September 1959, in Aachen, Germany

## SUMMARY

In the United Kingdom, regulations require that all supersonic flights should be made over the sea. When, for technical reasons, supersonic flights are required over land, each flight must be authorized by Flying Administration, Ministry of Supply. Within these regulations, a number of low-level flights and over 180 flights at heights between 35,000 and 45,000 ft have been made by the Fairey Delta 2 aircraft from the Royal Aircraft Establishment, Bedford, England. By careful control of the high-altitude flying, it has been possible to avoid damage almost completely and keep the number of complaints to an insignificant level. As the altitude is decreased, the risk of damage increases and at 10,000 ft and below, the cracking of glass and plaster may occur.

This report describes the tests made to measure the intensities of supersonic bangs over land, and the extent of damage that can be caused by such bangs.

## SOMMAIRE

D'après les règlements en vigueur au Royaume-Uni pour le vol des aéronefs, les seuls vols supersoniques autorisés sont ceux effectués au-dessus de la mer. Lorsque, pour des raisons techniques, on trouve nécessaire de survoler la terre à une vitesse supersonique, une demande d'autorisation est à adresser chaque fois au service 'Vols' du Ministry of Supply. Dans le cadre de ces règlements l'appareil Fairey Delta 2 a décollé du terrain du Royal Aircraft Establishment, Bedford, pour effectuer un grand nombre de vols à basse altitude, ainsi que plus de 180 vols à des altitudes comprises entre 35 000 et 45 000 pieds. Un contrôle rigoureux des vols à altitude élevée a permis d'éviter presque entièrement de provoquer des dégâts et de réduire à un niveau négligeable le nombre de plaintes reçues. La possibilité de provoquer des dégâts augmente avec diminution de l'altitude, et les vols à des altitudes de 10 000 et au-dessous risquent de provoquer des fêlures dans des fenêtres ou des fentes dans le plâtre. Dans ce rapport il s'agit des essais réalisés pour mesurer l'intensité des 'bangs' supersoniques produits au cours de vols au-dessus de la terre, ainsi que l'importance des dégâts que risquent de causer ces détonations.

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# EXPERIENCE OF SUPERSONIC FLYING OVER LAND IN THE UNITED KINGDOM

T.H. Kerr\*

## 1. INTRODUCTION

It is now about seven years since the first supersonic bangs were made by aircraft in dives in the United Kingdom. Since that time the number of aircraft capable of supersonic speeds in shallow dives and level flight has increased considerably and flying regulations have been introduced to keep the number of bangs and therefore the nuisance to the public and damage to property to an absolute minimum. These flying regulations at present simply state that all supersonic flights shall be made over the sea. If it is essential, for technical reasons, for supersonic flights to be made over the land, each flight must be authorised by the Ministry of Supply Flying Administration, after application has been submitted giving the height, Mach number and area over which the flight will take place.

Within these regulations, the Fairey Delta 2 aircraft has made a very large number of supersonic flights over land during the past three years. Most of the flights have been at altitudes between 35,000 and 45,000 ft but two exercises have been completed at low altitudes. During these flights, the bang pressures and impulses have been measured and compared with theoretical predictions and for a few of the flights at 10,000 ft the responses of typical buildings to supersonic bangs have been measured.

By careful correlation of the height, Mach number and the damage to property, it appears that the probability of damage from flights by the Fairey Delta 2 above 30,000 ft is negligible; the probability increases as the altitude is decreased down to 10,000 ft when some damage, window cracking etc., may occur; below 10,000 ft the probability of damage increases considerably and window and ceiling cracking is very liable to occur, but the cases of damage will be very sporadic. The higher probability of damage due to higher pressures at low altitude is nevertheless offset to a large extent by the limited lateral spread of the pressure pulse. By careful choice of track and accurate flying and control, the bang areas can be contained within the most sparsely populated districts.

During high altitude flying from Bedford, a very strict control of the aircraft track and reheat light-up point is maintained in order to avoid supersonic bang disturbances hitting large centres of population. This policy has proved quite successful up to the present time as the number of complaints and the incidence of damage have been extremely small.

## 2. TWO SERIES OF TESTS AT LOW ALTITUDE

### 2.1 Measurement of Bang Intensities from the Fairey Delta 2

Two exercises (see References 1, 2 and 3) to examine the pressure peaks and bang impulses made by the Fairey Delta 2 in level flight have been completed during the

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\* *United Kingdom*



past three years. The primary objective in each of the exercises was different. In the first case, the altitude and Mach number range covered were from 20,000 ft at  $M = 1.5$  down to 4,000 ft at  $M = 1.05$ . The measuring instruments were spread across the track in an effort to assess the spread and intensity of the bang as the altitude and Mach number were changed. In the second case, the altitude was kept at 10,000 ft and the Mach number to below  $M = 1.2$ . The instrumentation was spread along one mile of track in the hope that the flying would be controlled sufficiently accurately to place the points at which the bangs were expected to be loudest within this region. At the further end of this mile, two houses were instrumented to measure the response of typical buildings to pressure pulses.

Before discussing the results obtained in these tests, it is important to understand the methods of measurement and possible sources of error.

In the first series of tests, conducted by the Aeronautical Department of the Royal Aeronautical Establishment, a condenser type microphone was used and the incident pressures were measured by the changes in capacity and therefore changes in frequency of the gauge oscillator. The microphones were positioned with their diaphragms horizontal and about 10 in. above ground level (Fig.1). In the second series of tests, conducted by the Building Research Station, piezo-electric gauges were used as the pressure transducers. Some magnification of the load on the piezo-electric crystals was obtained by designing a light stiff diaphragm to receive the incident pressure and transmit the load to the crystals. A photograph of one of these pressure transducers and its position relative to the ground is shown in Figure 2.

In both cases the possible errors are: (a) the errors inherent in the calibration technique itself and the accuracy with which the pressure records can be measured, (b) the errors which arise due to the deflection of the shock induced flow around the microphone and (c) the errors arising from the incidence of the microphone relative to the shock front. For (a) it was considered that the sets of equipment used in the first and second tests would be able to measure pressures to within 7% and 5% respectively. For (b) the shock strengths were calculated to be insufficient for this effect to be a significant source of error. For (c) the mounting of the apparatus in each case was significantly different. By keeping the microphone 10 in. above the ground the test pressures appear to be approximately the same magnitude as 'free field' values in the first tests, whereas in the second series of tests, an attempt was made to measure the direct pressures applied to the ground or surface of a wall. The results show that the pressures measured were up to twice the calculated 'free field' values. Some pressure recordings from the first series of tests are shown in Figure 3. Runs 49, 42 and 44 are typical and fairly well defined 'N' waves and in the latter two cases were heard as double bangs. Run 6 is typical of an 'N' wave with rounded off peaks and which may be heard as a single or double bang or as a rumble. Run 33 is probably complicated by two 'N' waves modified by wind and refraction effects arriving within about 0.1 seconds of each other; the two audible bangs being made by the two sharp increments of positive pressure (the origin of the two 'N' waves is explained below). Pressure measurements from this type of record have been plotted and compared with those predicted by Randall (see References 1 and 4) for the aircraft in straight and level flight (Figs.4 and 5). It can be seen that there is reasonable agreement between the measured values and the 'free field' estimates for all flights in which the flight conditions are directly comparable with the theory. In all the other cases, it appears that refraction effects have considerably weakened the bang intensities.

During the second series of tests, when it was intended that the edge of the bang should be aimed within the area covered by the instrumentation, it was most probable that two 'N' waves would strike the ground within a very short interval of time. These two 'N' waves were developed during the acceleration; the first and generally stronger wave to reach an observer on the ground was developed later in the acceleration. This is shown pictorially in Figures 6 and 7. In Figure 6 a typical acceleration from  $M = 0.98$  to  $M = 1.2$  at 10,000 ft is shown and the line of propagations of the wave fronts (the rays) for each position of the aircraft is shown. The ray originating at  $M = 1.024$  forms part of the second 'N' wave arriving second at an observer on the ground; the rays originating at  $M = 1.05$ , 1.069 and 1.091 all arrive at the same position on the ground and if they arrive at exactly the same time might considerably enhance the pressures recorded at that point; from  $M = 1.111$  onwards the development of the sonic bang continues and this condition has been compared with the theoretical estimates in Figures 4 and 5. This typical acceleration has been redrawn in Figure 7 where the development of the shock fronts during the acceleration is shown. The single lines represent complete 'N' waves and generally the second 'N' wave is the weaker, with rounded pressure-time history. It is often heard only as a rumble soon after the double bang of the main 'N' wave has been heard. In some cases both 'N' waves have been recorded and one example of the time interval between the shocks is given in Figure 8.

In Figure 7 the relative position of the aircraft, observers and measuring points can be seen and the peak pressures in the first positive rise in pressure of the 'N' wave are also plotted against ground distance.

In general, the measured peaks are between 4 and 5 lb/sq ft, although the pressures do vary somewhat with distance. The calibrations of the instruments at these low reading points were checked and found correct and the variations of pressures must be caused by either refraction effects in the atmosphere or interference due to trees or houses etc. The highest pressures which might have occurred at about 7 miles from Bedford were not measured.

The effect of these bangs on the roof structure of some houses was measured by the Building Branch Station. The type of building used in the test is shown in Figure 8 and typical accelerometer records obtained are shown in Figure 9. The average acceleration measured normal to the roofs facing the bang was 0.7 'g' and the average peak to peak displacement was 0.040 in. The peak values measured during the test were 1.0 'g' and 0.087 in. respectively.

## 2.2 Damage and Physiological Sensations Caused by Sonic Bangs

During the course of these two experiments, a background of experience was built up on the physiological sensations and damage caused when certain peak pressures occur.

A bang was always heard when the rate of pressure rise was sufficiently large, i.e. not less than about 100 lb/sq ft/sec. In well defined 'N' waves the minimum peak to peak duration observed was 0.06 secs and this was associated with a double bang being heard. In other cases dull booms were heard; these seem to be associated with a pressure-time wave which has a rounded off positive peak and a low rate of rise of pressure from the negative peak (run 6 Fig.3).

The sharpness of the bangs was definitely determined by the sharpness of the 'N' profile of the pressure time waves. The low altitude high intensity bangs were like exceedingly loud cracks followed by rumblings and then engine noise; when heard the secondary bangs occurred during this period.

The very loud bangs (run 44 Fig.3) were similar in sound to close gunfire; a distinct pressure was felt on the chest and the ears were left momentarily ringing and there was a distinct impression that the ground shook. Even though the arrival of the bangs was expected within a second or so, the occurrence of the high intensity bangs was still startling. Table 1 summarises the effects of the bangs and physiological sensations and damage during the tests.

### **3. CONTROL OF THE HIGH LEVEL FLYING OF THE FAIREY DELTA 2 FROM THE R. A. E., BEDFORD**

Two Fairey Delta 2 aircraft have been operating from the R.A.E. in Bedford for over two years now and during that time approximately 180 supersonic flights have been made over land in the Bedford area. Most of the flights have been made at altitudes between 35,000 and 40,000 ft, although some have been made at 30,000 ft and seven at 10,000 ft. During all these flights the aircraft has been under radar control. From take-off, the aircraft is climbed in a south westerly direction and vectored onto a predetermined track for the particular flight. The pilot is told when he is on track and when to light reheat and start the acceleration to supersonic speeds. Two examples of the track of the aircraft on typical supersonic flights are given in Figures 10 and 11. The shaded areas on each side of the track, where it is predicted that the supersonic bangs will be heard, have been graded to indicate the places where the louder bangs may occur. Outside the edges of the area, the bangs will not be heard.

All these efforts to keep the nuisance to an absolute minimum have been rewarded in that the amount of damage caused has been negligible (i.e. less than £10 total) and the number of complaints has been very small. In general these complaints have originated from people living within a few miles of the track where the bangs are always sufficient to cause people to start or jump. Most complaints have arisen when three flights have been made in one day. Complaints which arrive at the airfield by telephone are generally satisfied when a brief explanation of the need to do the work is given and an apology made for the disturbance.

Supersonic flying has thrown a much greater responsibility and load of work on Air Traffic Control. During these research flights, it was essential to keep the aircraft under continuous radar cover, as the pilot was, in effect, flying blind by having to concentrate, for most of the time, on his instruments. As he also covered large distances in a very short time and fuel was used at a very rapid rate, it was essential that Air Traffic Control keep a careful check of the positions of the aircraft relative to base so that, knowing the fuel state, they could recall the aircraft in time to enable it to return to base with a safe margin of fuel. These conditions will apply in service operations as well as in the research testing which has been described.

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3. Newberry, G.W.      *The measurements of sonic bangs and their effect on typical buildings.* Building Research Station Note No.B.180, Dec 1957. (Unpublished).
4. Randall, D.G.      *Methods of estimating distributions and intensities of sonic bangs.* Unpublished M.O.S. Report.

TABLE 1  
Summary of Bang Pressures

<i>Test series</i>	<i>Altitude (ft)</i>	<i>Mach number</i>	$\Delta P$ <i>measured (lb/sq ft)</i> <i>1st peak</i>	<i>Sensations</i>	<i>Damage</i>	<i>Run no.</i>
1	31,810	1.5	0.57	{ Dull booms heard, enough to cause a slight start.	Nil	6
1	26,950	1.47	0.57		Nil	49
1	13,830	1.11	1.89	Two bangs heard	One or two cracked windows	33
2	10,000	1.11	4.6*	Two bangs heard	No windows broken throughout tests. One door cracked due to slamming when slightly ajar.	
1	9,370	1.07	1.65	Two bangs heard	Some cracked windows.	42
1	6,130	1.08	4.05	Very loud double bangs like close gunfire. Singing in ears and shaking of ground.	Some broken windows and cracked ceilings.	44

\* These measurements were made at the ground surface and are probably of the order of twice 'free field' pressures.

*Note:* Other evidence of damage caused by supersonic bangs has been obtained from the major incidents which have received wide publicity in the national press. In all these cases, when the cause of damage was clear, it has been found that the aircraft were flown (generally accidentally) at supersonic speeds at heights around 10,000 ft or below.

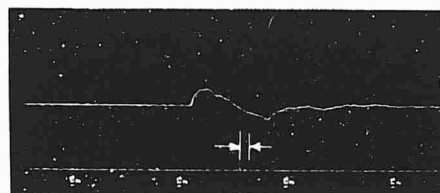


Fig.1 Installation of the microphone and oscillator box in the first series of tests



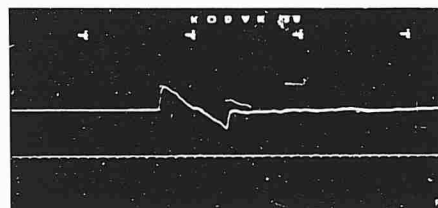
Fig.2 Installation of the piezo-electric gauges in the second series of tests

TIME MARKS .01 seconds



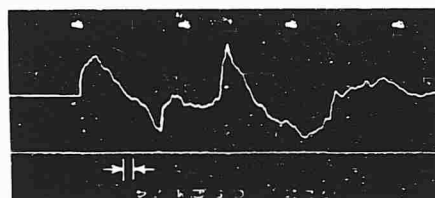
RUN No.6 ONE BANG HEARD  
 HEIGHT 31,180 feet  
 M. 1.5

+0.57<sup>↑</sup> -0.49<sup>↑</sup>  
 lb/ft<sup>2</sup> lb/ft<sup>2</sup>



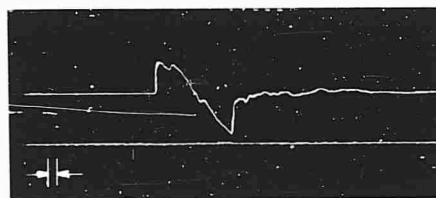
RUN No.49 DULL BOOM HEARD  
 HEIGHT 26,950 feet  
 M. 1.47

+0.87<sup>↑</sup> -0.73<sup>↑</sup>  
 lb/ft<sup>2</sup> lb/ft<sup>2</sup>



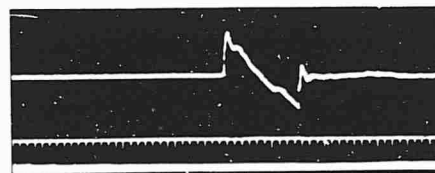
RUN No.33 TWO BANGS HEARD  
 HEIGHT 13,830 feet  
 M. 1.11

+1.89<sup>↑</sup> -1.61<sup>↑</sup>  
 lb/ft<sup>2</sup> lb/ft<sup>2</sup>



RUN No.42 TWO BANGS HEARD  
 HEIGHT 9,370 feet  
 M. 1.07

+1.14<sup>↑</sup> -1.65<sup>↑</sup>  
 lb/ft<sup>2</sup> lb/ft<sup>2</sup>



RUN No.44 TWO BANGS HEARD  
 HEIGHT 6,130 feet  
 M. 1.08

+4.05<sup>↑</sup> -3.90<sup>↑</sup>  
 lb/ft<sup>2</sup> lb/ft<sup>2</sup>

Fig.3 Some pressure recordings obtained during the first trials

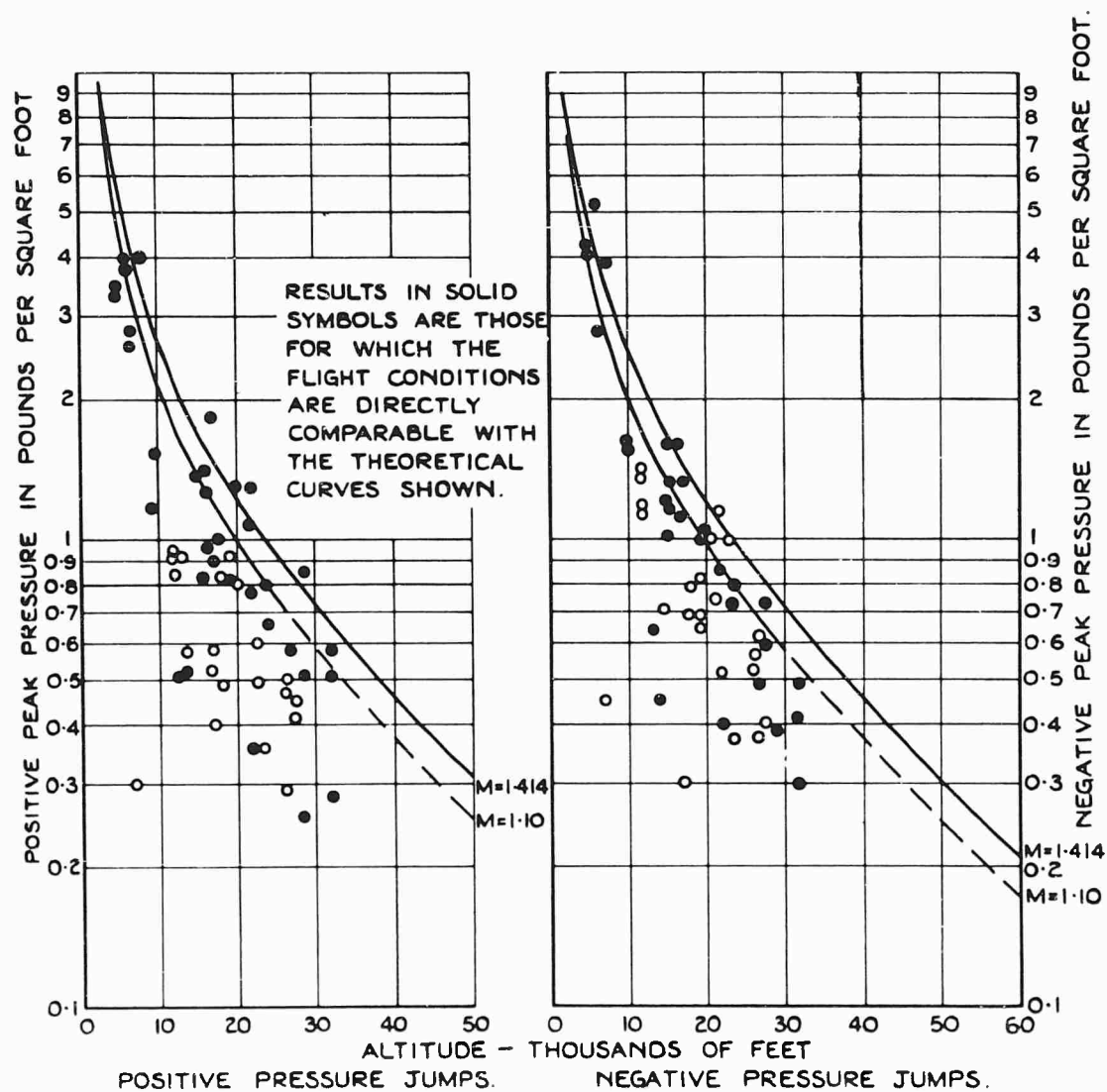


Fig.4 A comparison of the observed peak bang pressures with the theory of Warren for steady level flight



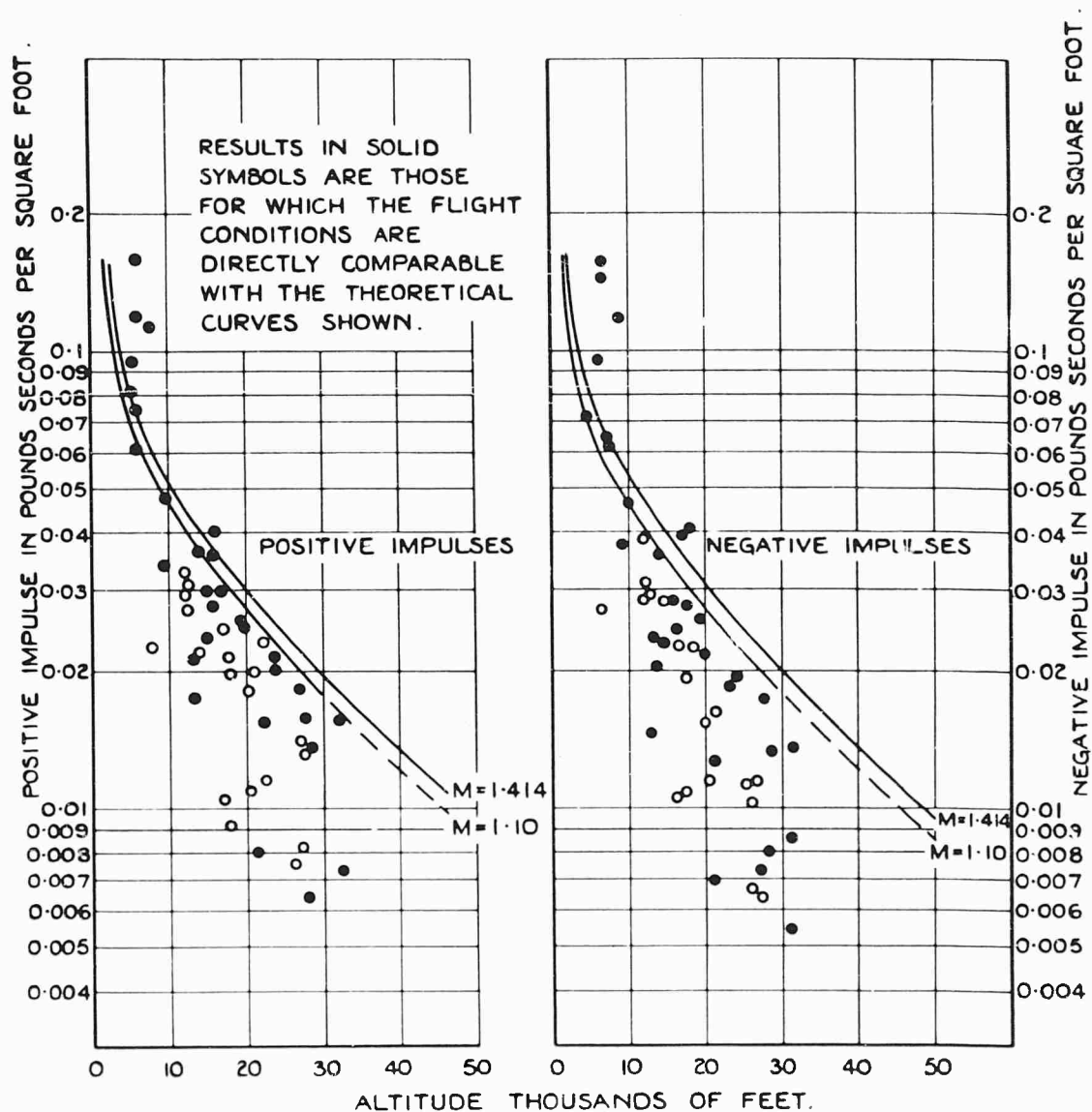


Fig.5 A comparison of the observed bang impulses with the theory of Warren for steady level flight

TIME, SECS.	0	3	6	9	12	15	18	21	24	27	30	33
MACH. N°	0.98	1.024	1.050	1.069	1.091	1.111	1.131	1.148	1.160	1.171	1.184	1.194

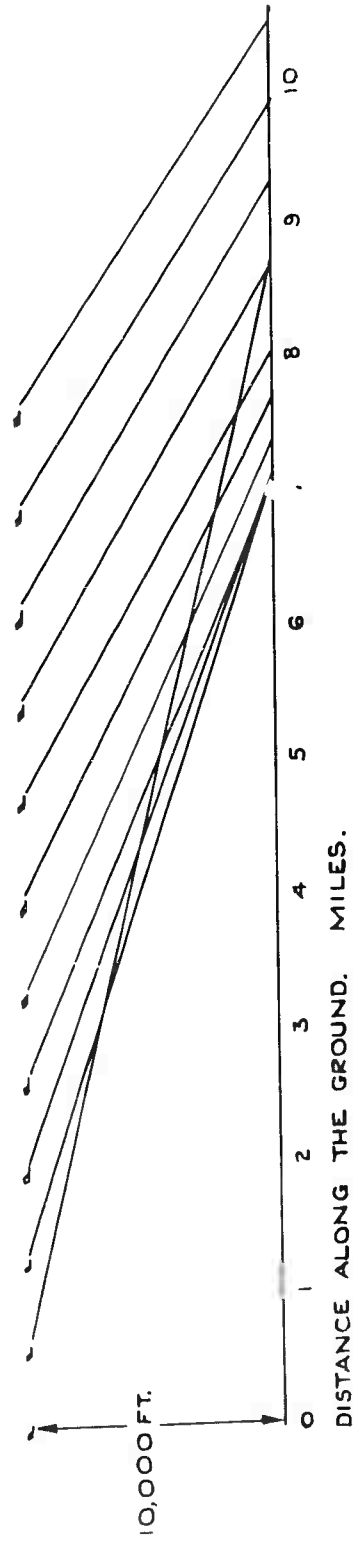


Fig. 6 A pictorial presentation showing the line of propagation of the wave fronts at each aircraft position

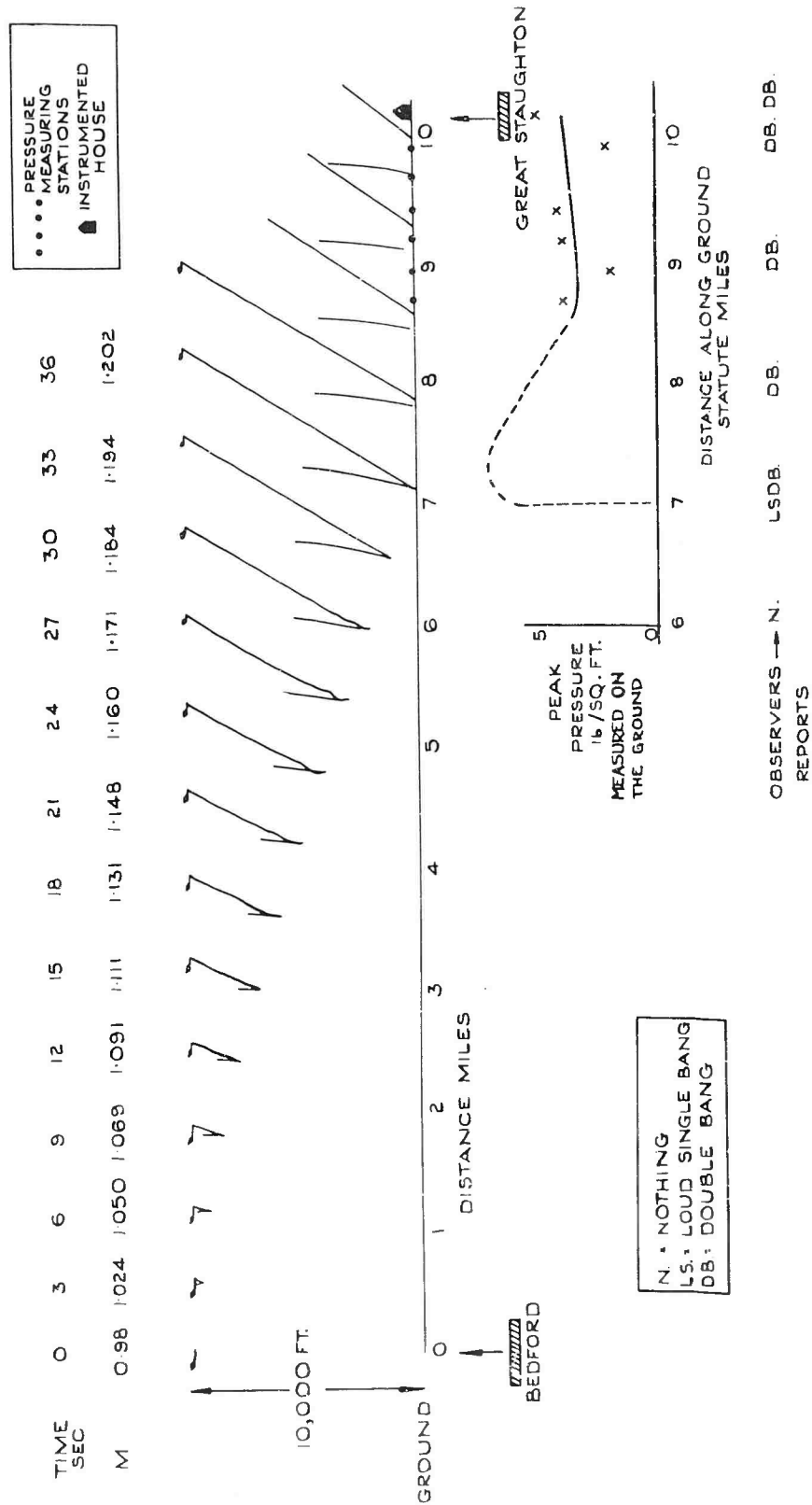


Fig.7 A time history of a level flight acceleration from  $M = 0.98$  to  $M = 1.2$  at 10,000 ft

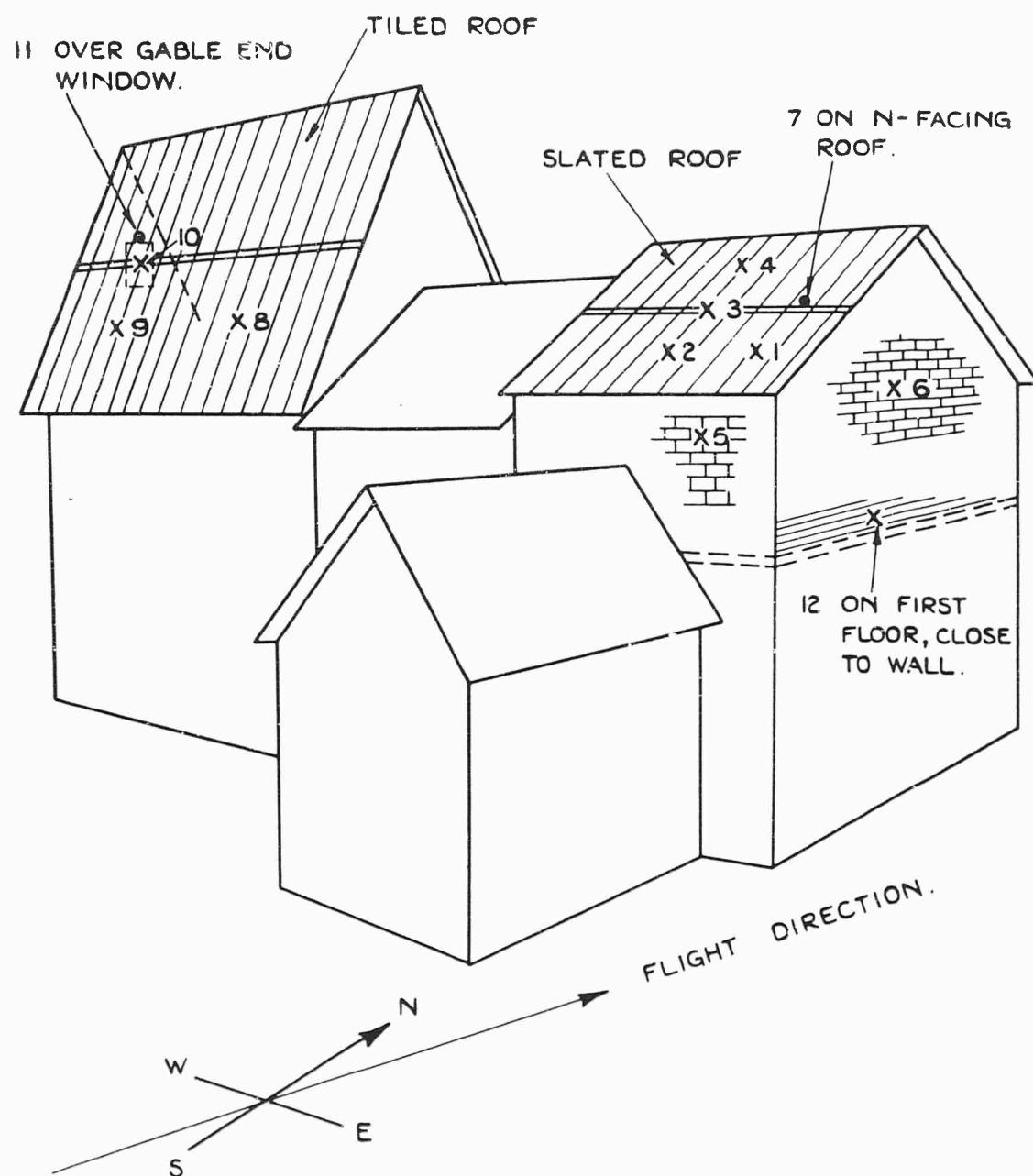


Fig.8 Positions at which vibration measurements were taken on houses

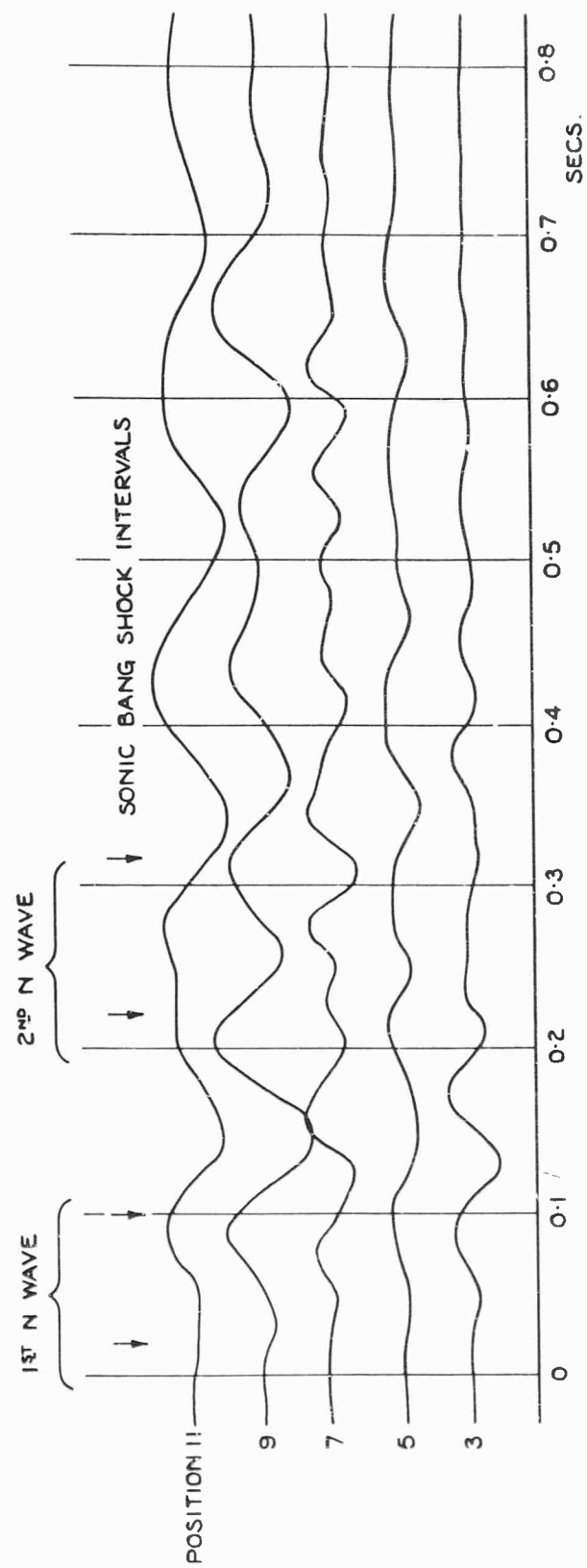
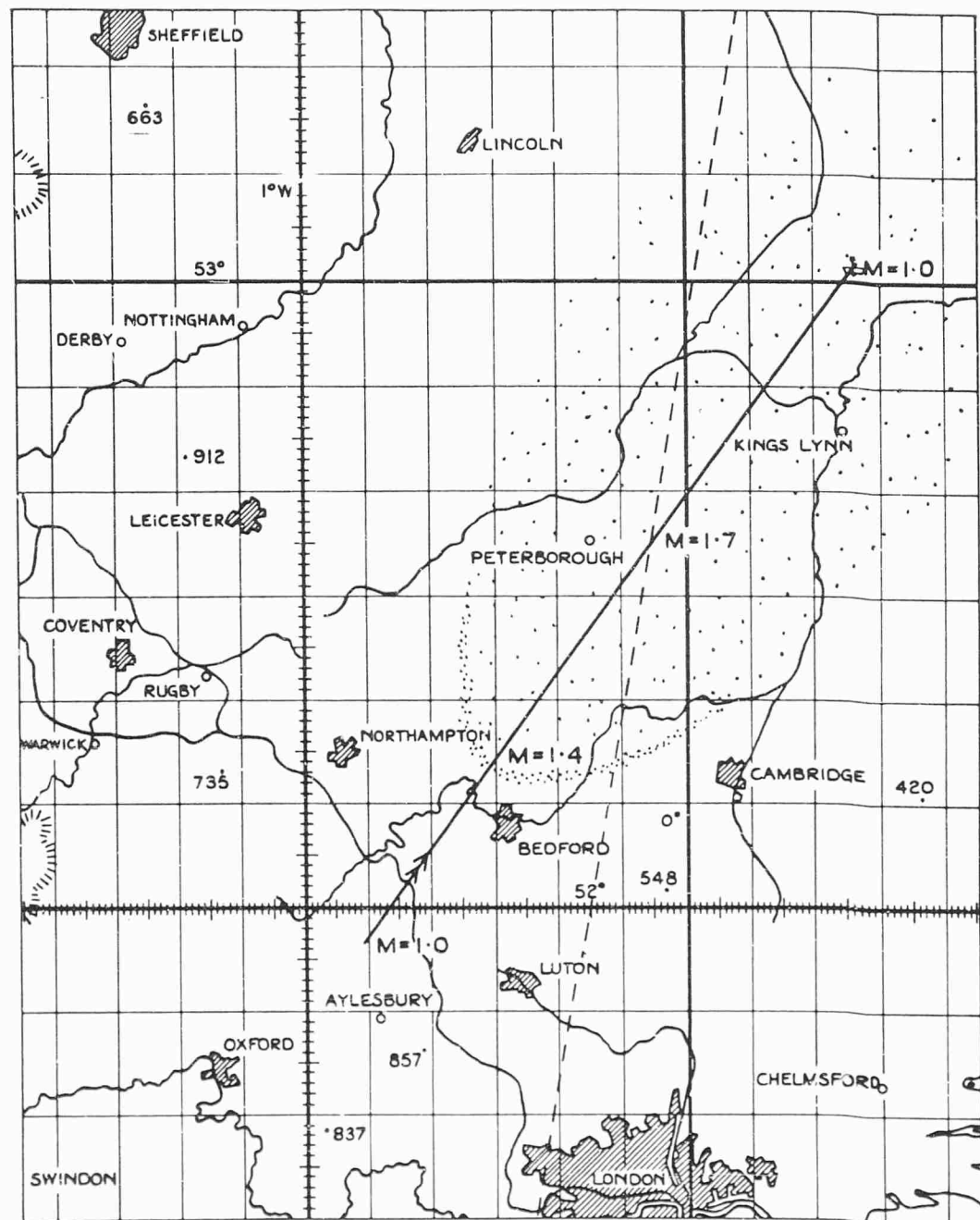


Fig. 9 Building vibration amplitude records



AIRCRAFT TRACK.



SUPERSONIC BANG AREA.

MORE INTENSE AREAS INDICATED  
BY CLOSER SPACED DOTS.

Fig.10 A typical track for a straight supersonic acceleration and deceleration

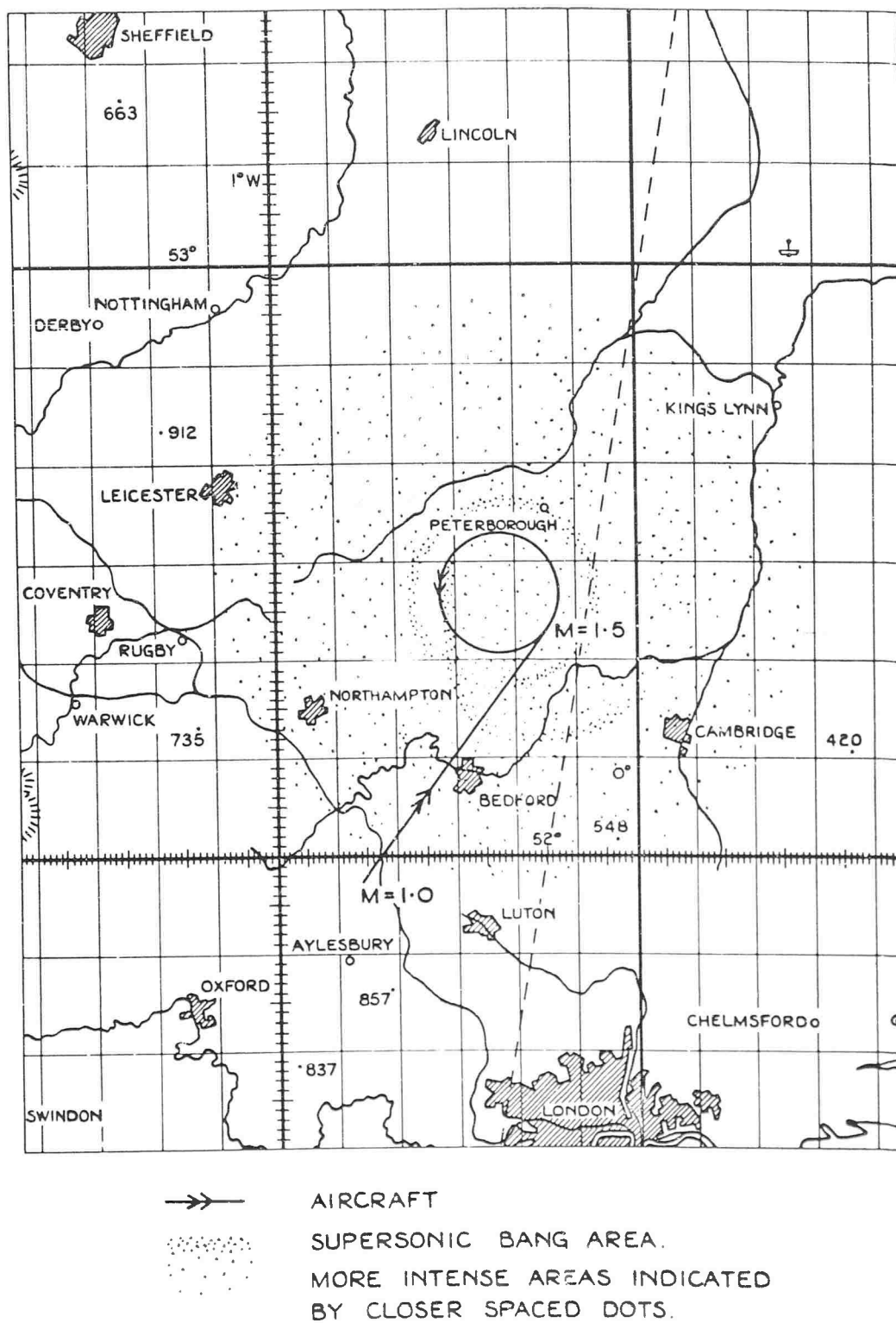


Fig.11 A typical track for a straight supersonic acceleration up to  $M = 1.5$  & then a  $2g$  turn at  $M = 1.5$

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